Extended Abstract -- National Tsunami Hazard Mitigation Program Workshop on tsunami hazard, risk, and vulnerability

Title – Societal vulnerability to tsunamis – overview and relationship to a national risk analysis

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This presentation provides an overview of vulnerability science as it relates to tsunamis, including a discussion of how it may be useful in the development of a national tsunami risk analysis and in the implementation of the TsunamiReady™ Program (*Slide 1*). The National Tsunami Hazard Mitigation Program (NTHMP) strives to help communities reduce the negative consequences of future tsunamis, including mortality and property loss. To develop life-saving strategies in their communities, managers need to understand how their at-risk populations are vulnerable to future tsunamis. Information on the potential for future events and hazard-zone delineations is critical but typically not enough to initiate behavior change in at-risk communities. Managers also require vulnerability data that translates natural-science information, such as geologic recurrence intervals and hazard-zone delineations, into actionable society-relevant information. Vulnerability information provides managers with the means to depart from one-size-fits-all education and mitigation strategies that inadequately address differences in community context and needs.

Vulnerability as a science involves examining the combination of physical, social, economic, ecological, and political components that influence the degree to which an individual, community, or system is threatened by a particular event, as well as their ability to mitigate these threats and recover when an event occurs (*Slide 2*). Population vulnerability to future tsunamis is a function of three components – *exposure, sensitivity,* and *adaptive capacity* (Cutter, 2003; Turner et al., 2003). Population exposure is related to hazard proximity and the physical characteristics of the tsunami (e.g., arrival times, spatial extent). Sensitivity refers to differential degrees of potential harm among at-risk populations, based on the internal characteristics of an individual, group, or socioeconomic system. Adaptive capacity describes possible adjustments and responses of a system to reduce a population’s exposure or sensitivity. Each of these elements has a strong spatiotemporal component in which geospatial analysis can help simplify complex, interwoven relationships among important factors. The following sections further describe the three components of vulnerability from the tsunami perspective.

Population ***exposure*** is the most straight-forward of the three components and is largely a question of spatial coincidence – for example, are there people in tsunami-prone areas and if so, how many are there? In a geospatial setting, this is answered with simple overlays of demographic data (e.g., U.S. Census blocks with population counts) and hazard zones to identify the number of people and hot-spots of high population density (*Slide 3*). The figure in Slide 3 is a bar graph summarizing community variations in residential exposure to tsunami hazards along the open-ocean Washington coast. The slide also lists other types of people that can be in tsunami-prone areas, such as beach visitors or employees at local businesses. Examples of published reports that include estimates of population exposure to tsunamis include the USGS reports written for Oregon (Wood, 2007), Washington (Wood and Soulard, 2008), Hawaii (Wood et al., 2007), and California (Wood et al., in review). *Slide 4* shows an example of a relative ranking of community exposure based on the number and percentage of various population-related attributes that are in these reports. From a TsunamiReady™ perspective, population-exposure information helps emergency managers to target where outreach, preparedness plans, and mitigation strategies may be most warranted.

Population ***sensitivity*** can be inferred using demographic data in a GIS analysis to identify the type of people in tsunami-prone areas, not only the number of at-risk populations (exposure). Certain demographic characteristics may influence one’s ability to prepare for or respond to tsunamis. For example, 45% of residents in the tsunami-prone areas of the City of Bandon, Oregon, are over 65 years in age (Wood 2007), and these older residents may have difficulty in evacuating in the time between earthquake ground shaking and wave arrival, although this sensitivity effect may be tempered by research findings that greater knowledge of response actions often accompanies increasing age. The aforementioned USGS reports include inventories of demographic attributes, such as age, gender, race, and socioeconomic status, for populations in the tsunami-prone areas of the various states. Wood et al. (2010) summarizes a geospatial approach for identifying hot-spots of demographic sensitivity to tsunamis using statistical methods that address the multivariate nature of at-risk populations (*Slide 5*). For example, high numbers of children, high numbers of renters, and low income levels are all indicators of heightened sensitivity but will amplify each other if they are all present in the same census block. From a TsunamiReady™ perspective, information on demographic sensitivity helps emergency managers determine not only where but also the types of risk-reduction actions are needed. For example, preparedness planning for an at-risk population comprised primarily of older individuals may need to address the potential limited mobility or pre-existing health issues of the population.

The ***adaptive capacity*** of at-risk populations to future tsunamis is a function of what at-risk individuals are able to and can do in light of potential threats (*Slide 6*). One example of geospatial research to study adaptive capacity is pedestrian-evacuation modeling, which can be done to estimate the amount of time required to escape tsunami-prone areas to high ground before tsunami-wave arrivals (Wood and Schmidtlein, 2012). This information can then be merged with demographic data to compare population exposure of several communities as a function of travel time to safety (*Slide 6*). From a TsunamiReady™ perspective, emergency managers can use evacuation-modeling results to identify appropriate risk-reduction strategies. In areas where modeling indicates successful evacuations are possible, managers can use results in outreach efforts to raise positive outcome expectancy in at-risk individuals (i.e., people are more likely to participate in evacuation training if they believe their efforts will have a positive outcome). In areas where modeling results suggest evacuations are not likely to be successful, mitigation efforts, such as vertical evacuation berms or buildings, may be warranted to save lives. Another critical element of adaptive capacity is the perceptions of at-risk populations. The perceptions and willingness of at-risk individuals to take action are significant factors in whether or not they may want to pursue TsunamiReady™ recognition.

Vulnerability assessments can help advance the development of a national tsunami risk analysis in several ways (*Slide 7*). The traditional risk definition involving joint probabilities and asset value are useful for structures but is incomplete when attempting to address the non-structural and non-economic aspects of risk. For example, perceptions and tolerance of risk are important elements of understanding broader societal risk, as are impacts to quality of life and livelihoods. Risk has been described as actuarial and useful for cost-benefit analysis, whereas vulnerability describes actual pre-event conditions that can be modified to lower the potential for loss (Sarewitz et al., 2003).

Vulnerability is also useful when dealing with “black swan” problems (*Slide 8*), which are unexpected events of large magnitude and consequence that dominate history and shifts in public policy but are considered outliers in a pre-event risk assessment (Taleb, 2007). Recent examples include the terrorist attacks of September 11, 2001, and aspects of the 2005 Hurricane Katrina disaster. These events were surprises to most people affected, had major impacts, and were rationalized by hindsight, as if they could have been expected. For example, relevant data may have been available but unaccounted for in pre-event, risk-reduction efforts. Large, destructive tsunamis often fall in the same category, where catastrophic events are possible but the long return intervals measured in hundreds of years make them seem unlikely in the near future from a probabilistic perspective. This begs the question of whether different criteria for future risk assessments are needed (*Slide 9*). For example, if the goal is to minimize economic losses from a tsunami over the long term, then perhaps a probabilistic approach is appropriate. However, if the goal is to minimize life loss from future tsunamis, then a plausible worst-case scenario may be more appropriate for delineating tsunami-hazard zones.

Characterizing population risk is also complicated by the high number and dynamic nature of individuals in tsunami-prone areas (*Slide 10*). The photographs in the slide show various types of “service” populations in tsunami-prone areas, such as (a) beach visitors, (b) tourists at coastal boardwalks, (c) military personnel, (d) tourists in harbors and on cruise ships, (e) boaters, and (e) university students. As a national tsunami risk analysis takes shape, it will need to address these service populations because traditional risk assessments typically only focus on residential populations.

Distinctions in the societal context between far-field and near-field tsunamis should also be addressed in a national tsunami risk analysis *(Slide 11)*. Traditional risk assessments quantify the probability of some level of damage to societal assets over a given period, which is appropriate for structural and economic concerns. However, the level of threat a tsunami scenario presents to people is a function of the amount of time required for people to evacuate and the time before wave arrival. For example, population risk will vary depending on if they have 20 minutes to evacuate (in the case of some near-field threats) or 4 hours (in the case of some far-field threats). Therefore, the type of tsunami threat and the adaptive capacity of at-risk populations will need to be addressed in some way when characterizing population risks from tsunamis. Related to this issue is the need to capture non-mortality issues, such as psychological impacts, loss of livelihoods, loss of cultural assets, and loss of ecosystem goods or services (*Slide 12*). Community recovery from a tsunami may also be complicated if the landscape is dramatically transformed, such as expected subsidence after a near-field earthquake.

A national tsunami risk analysis could benefit the nation in many ways, such as prioritizing risk-reduction efforts and funding by geography, by tsunami type (e.g., near- or far-field), and by adaptation strategy (e.g., education, mitigation, warning systems) (*Slide 13*). A traditional risk approach based on joint probabilities and loss estimates will be an integral element to that national risk analysis. However, to properly characterize population-related risks, a national tsunami risk analysis will need to distinguish between near-field and far-field tsunami threats from the perspective of evacuation potential. Multiple tsunami scenarios may be needed to simultaneously address different societal goals, such as economic loss avoidance and minimizing human fatalities. Furthermore, a national tsunami vulnerability assessment that inventories the number and type of at-risk populations and accounts for evacuation potential in areas with near-field tsunami threats may be an appropriate first step towards a national risk analysis. An initial focus on vulnerability provides managers with actionable information in light of incomplete knowledge of the probability of future events, economic impacts, and mortality, which are critical to moving towards a true risk analysis.

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